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RESEARCH ARTICLE

ANALYSIS OF SERIES RESISTANCE AND INTERFACE STATE DENSITIES OF Ru/Ti/n-InP SCHOTTKY DIODE.

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Abstract

The electrical properties of Ru/Ti/n-InP Schottky diode are investigated at room temperature using current-voltage (I-V) characteristics. The characteristic parameters of the Schottky barrier diode like barrier height, ideality factor and series resistance have been determined from the I-V measurements. The values of barrier height obtained from Norde's function were compared with those from Cheung functions, and observed that there was a good agreement between them. However, the values of series resistance obtained from Cheung functions and Norde's functions are not coincidence with each other. Because, Cheung functions are applicable in non-linear region of the forward bias I-V characteristics. Also, the energy distribution of interface state density was determined from the forward bias I-V characteristics by taking into account the bias dependence of the effective barrier height. The results reveals that the formation of thin interfacial layer between the metal and semiconductor.

Introduction:-

InP is an extremely suited substrate for a large number of applications such as high-temperature, high-frequency and high-power devices due to a direct transition optimum band gap and high-electron mobility (Roderick and Williams., 1998). Indeed, the investigations on Schottky contacts on n-type InP so far have yielded barrier heights in the range of 0.4-0.55 eV. This may be the chemical reaction and/or out-diffusion occurring on the metal–InP interface producing interfacial layers. This contributes to the barrier by local charge redistribution and/or effective work function change at the interface (Freeouf and Woodall., 1981). Consequently, the development of high quality metal-semiconductor (MS) structure is very important since the electrical characteristics of the Schottky barrier diode (SBD) strongly depend on the quality of MS interface. Thus, the formation of Schottky contacts to InP with high barrier height and low-reverse leakage current is still a scientific challenge. I–V characteristics are linear in the forward bias at low voltages, but sometimes it deviates from linearity due to the effects of the series resistance, R_S and interface states when high voltage is applied. The parameter R_S is only effective in the downward-curvature region (non-linear region) of the forward I–V characteristics but parameters such as the barrier height, ϕ_b and ideality factor n are effective in both the linear and non-linear regions (Bardeen, 1947). The analysis of barrier heights with different metallization schemes as a function of the metal work function examined the effects of the interface layer on the ideality factor of the forward bias I-V characteristics (Sze, 1981). As we know, a thin interfacial native oxide layer is formed between the metal and the semiconductor in the processing of a Schottky barrier diode (SBD). These influences on the diode characteristics as well as the interface states (Spicer et al., 1980) Therefore, the interfacial layer and the interface states play an important role in the determination of the barrier height. Consequently, it has been concluded that the barrier height determined from the I-V characteristics controlled by the interface states energy distribution in equilibrium with the semiconductor and the applied voltage under forward bias condition.

In the present work, our main objective is to fabricate and analyze the behaviour of different electrical parameters of Ru/Ti/n-InP Schottky barrier diode. Indium is chosen as ohmic contact and Ru/Ti metals are chosen for rectifying bilayer contact. The electrical parameters like Schottky barrier height, ideality factor, series resistance and interface states were studied by I-V method at room temperature.

Experiment:-

A cleaned and polished n-type InP substrate of thickness 350 µm was used to prepare Ru/Ti Schottky contact at room temperature in this study. The wafer was chemically cleaned with trichloroethylene, acetone and methanol by means of ultrasonic agitation. This method removes the unwanted impurities on wafer and protects surface damage. Every layer happens to perform these cleaning processes for 5 min duration and rinsed in deionised (DI) water after cleaning. Later the wafers are dried with high-purity nitrogen. Also, InP wafer was etched with HF (49%) and H_2O with ratio 1:10 for the period of 60 s to remove the oxides from surface of wafer. Again the wafer was rinsed in DI water for 30 s and dried in N_2 flow. The low resistivity ohmic contact was formed on the backside of InP wafer by deposition of high purity (99.99%) indium (50 nm) metal. The e-beam evaporation system was used to evaporate Ti (20 nm) and Ru (30 nm) as first and second layers on the polished side of the n-type InP wafer. A stainless-steel mask was used for deposition under this evaporation system. The pressure of about 5.0×10^{-6} mbar (Canali et al., 1977) was kept for the entire evaporation process in vacuum coating unit at the mentioned temperature. Keithley source measuring unit (2400) was used to study the current–voltage (I-V) characteristics of the investigated Ru/Ti/n-InP Schottky barrier diode.

Result and Discussion:-

I-V characteristics:-

Fig. 1 shows the forward bias I-V characteristics of the Ru/Ti/n-InP Schottky barrier diode (SBD) at room temperature. From this study the reverse leakage current of Ru/Ti/n-InP SBD is determined to be 7.986×10^{-10} A at −1 V. The thermionic emission across the Schottky diode with the series resistance (R_S) gives the forward-bias current as (Canali et al., 1977):

$$I = AA^{**}T^2 \exp\left(-\frac{q\phi_b}{kT}\right)\left[\exp\left(\frac{qV}{nkT}\right)-1\right] \quad (1)$$

The above can be modified as

$$I = I_0 \exp\left(\frac{qV - IR_S}{nkT}\right) \quad (2)$$

where I_o is the saturation current, T is temperature in Kelvin, n is ideality factor, A** is effective Richardson constant, k is Boltzmann's constant, R_S is series resistance, ϕ_b is Schottky barrier height and A is the area of contact. The value of ϕ_b can be deduced directly from the I-V curves if the effective Richardson constant, A** is known. The literature value of A** to n-InP is 9.40 $Acm^{-2} K^{-2}$ (Sze, 1981). From Fig. 1, the ideality factor n and the Schottky barrier height ϕ_b can be calculated using a linear curve fit of ln(I) versus V. The ideality factor was determined from the slope of the forward bias I-V characteristics in Fig. 1 through the relation:

$$n = \left(\frac{q}{kT}\right)\left(\frac{dV}{d(\ln I)}\right) \quad (3)$$

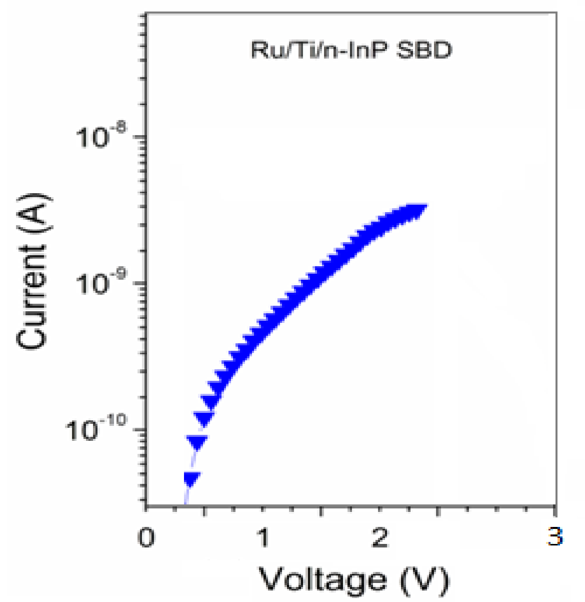

Fig. 1:- Forward current–voltage characteristics of Ru/Ti/n-InP barrier diode.

Generally, the ideality factor value is equal to unity for ideal diode. The current axis intercept and slope of the linear region of forward-bias I-V plot are used to determine the Schottky barrier height and ideality factor the ate taken in to consider. The experiment describes the ideality factor value as greater than unity. This is due to the presence of the interfacial thin layer, wide distribution of low-SBH patches and series resistance effect. Also, Schottky barrier height depends on the bias voltage. The zero-bias barrier height ϕ_b, can be calculated from the following equation:

$$\phi_b = \frac{kT}{q}\ln\left(\frac{AA^{**}T^2}{I_o}\right) \quad (4)$$

The dark current-voltage (I-V) characteristics give information on the rectifying diode behavior, the leakage current and the series resistance of the device. It is clear from the Fig.1 that a good diode exhibits rectifying behavior. However, the plot is deviating from linearity at high-applied voltage region. This deviation may be due to the voltage drop across the series resistance in the region of the semiconductor. The investigated diode Schottky barrier height (SBH) is 0.83 eV and ideality factor is 1.18 studied from I-V measurements. The calculated ideality factor is larger than unity, which is ascribed to secondary mechanisms that include interface dipoles due to interface doping (Rajagopal Reddy et al., 2011). Also, the presence of a wide distribution of low-SBH patches may be the other reason (Monch, 1999). The other reasons leads to an ideality factor greater than unity are image-force effect, recombination-generation etc. (Munikrishna Reddy et al., 2015). The values of Schottky barrier height (ϕ_b), ideality factor (n) and series resistance (R_S) can be calculated precisely using the method developed by Cheung (Cheung and Cheung, 1986). The Cheung's functions are given as:

$$\frac{dV}{d(\ln I)} = IR_S + n\left(\frac{kT}{q}\right) \quad (5)$$

$$H(I) = V - n\left(\frac{kT}{q}\right)\ln\left(\frac{1}{AA^{**}T^2}\right) \quad (6)$$

and

$$H(I) = IR_S + n\phi_b \quad (7)$$

These equations should give a straight line for the data of non-linear (downward curvature) region in the forward bias I–V characteristics. The experimental dV/d(ln I) versus I, and H(I) versus I plots for the Ru/Ti/n-InP Schottky diode are shown in Fig. 2 and Fig. 3 respectively. The values of ideality factor (n) and series resistance (R_s) are found to be 1.37 and 47 MΩ from the dV/d(ln I) versus I plot. A plot of H(I) versus I will also give a straight line.

The slope of this plot provides a second determination of Rs, which can be used to check the consistency of Cheung's approach. Thus, by using the value of the ideality factor obtained From equation 7, the value of barrier

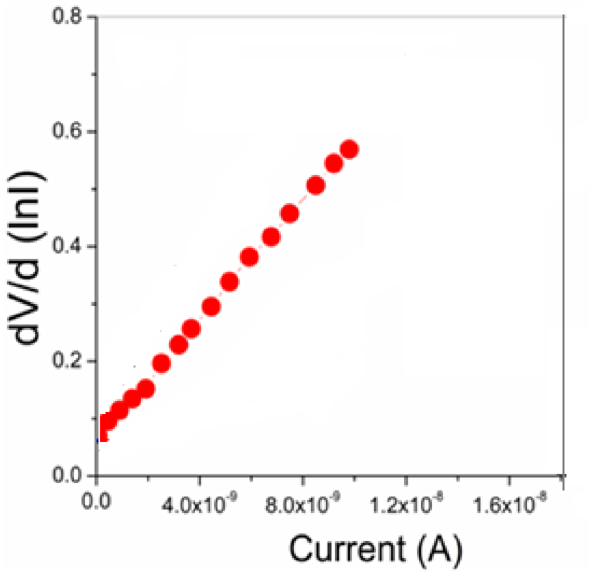

Fig. 2:- Plots of dV/d(lnI) versus I of Ru/Ti/n-InP Shottky diode

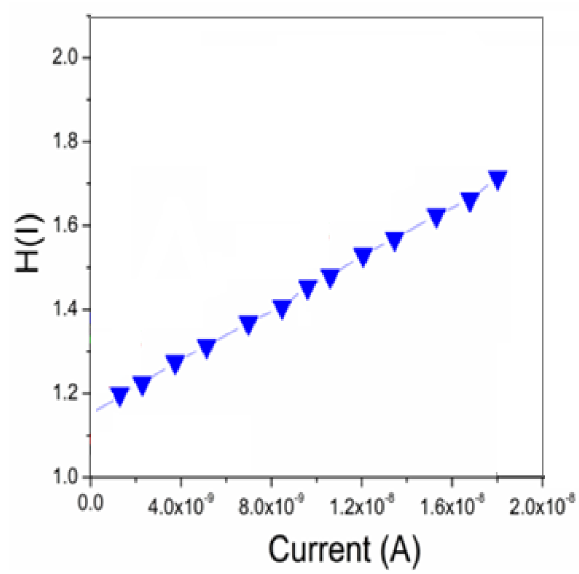

Fig.3. Plots of H(I) versus I of Ru/Ti/n-InP Shottky diode.

height (ϕ_b) can be calculated from the y-axis intercept of the H(I)-I plot. From H(I) versus I plot, ϕ_b and R_S are calculated as 0.85 eV and 56 MΩ respectively. Thus, it is clear that there is a considerable difference between the ideality factors of I-V data in different regions. Also, series resistance, R_S values calculated by Cheung's method and they are well coincidence with each other.

The modified Norde function (Norde, 1979) is also used to determine SBH and R_S. The mathematical expressions are given by

$$F(V) = \frac{V}{\gamma} - \frac{1}{\beta}\ln\left[\frac{I(V)}{AA^{**}T^2}\right] \quad \mathbf{8}$$

$$\phi_b = F(V_0) + \frac{V_0}{\gamma} - \frac{kT}{q} \quad \mathbf{9}$$

$$R_S = \frac{kT(\gamma - n)}{qI_{\min}} \quad \mathbf{10}$$

The equations 9 and 10 hail the values of SBH and R_S and the founded values are 0.87 and 17 MΩ. Thus the calculated SBH value from Norde function is very close with I-V characteristic and Cheung's function. Similarly, a closed R_S is obtained while studies in relation between Norde function and Cheung's functions.

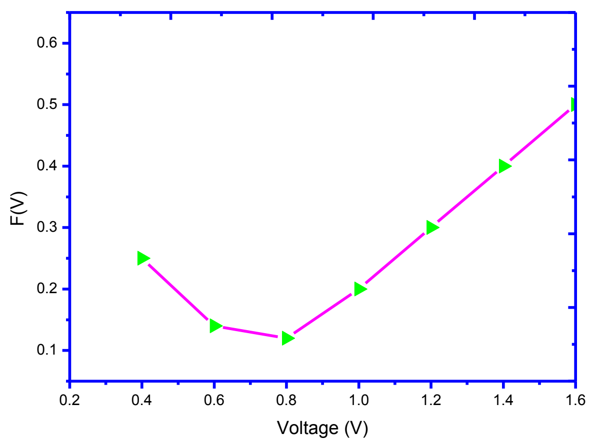

Fig.4:- Modified Norde plot of the Ru/Ti/n-InP Schottky barrier diode obtained from forward I-V characteristics.

Determination of Interface States Density (N_{SS}):-

The density distribution of the interface states N_{SS} in equilibrium with the semiconductor can be determined from the forward bias (I-V) data by taking the voltage dependent ideality factor n and barrier height ϕ_b into account. For a diode, the ideality factor n becomes greater than unity as proposed by Card and Rhoderick (Card and Rhoderick, 1971):

$$n(V) = I + \frac{\delta}{\varepsilon_i}\left[\frac{\varepsilon_S}{W} + qN_{SS}\right] \quad \textbf{11}$$

where N_{SS} is the density of interface states, ε_s=11.4 ε_o and ε_i =3.5 ε_o are the permittivity of the interfacial layer and semiconductor. In n-type semiconductors, the energy of the interface states with respect to the top of the conduction band at the surface of the semiconductor is given by:

$$E_c - E_{SS} = q(\phi_b - V) \quad \textbf{12}$$

Fig. 5 shows the energy distribution profile of N_{SS} as obtained from the forward bias I-V data by using equation 11 of the diode at room temperature. As can be seen in Fig.5, the exponential growth of the interfacial state density is very apparent. The density of interface states of the diode studied is of the order of 4.00486×10^{12} cm^{-2} eV^{-1}. The density of the interface states of the studied diode is lower than that of other literature Schottky diodes with a native interfacial insulator layer (Tyagi, 1991). Experimental results show that the interface states, interfacial layer play an important role in the determination of barrier parameters of the Schottky devices.

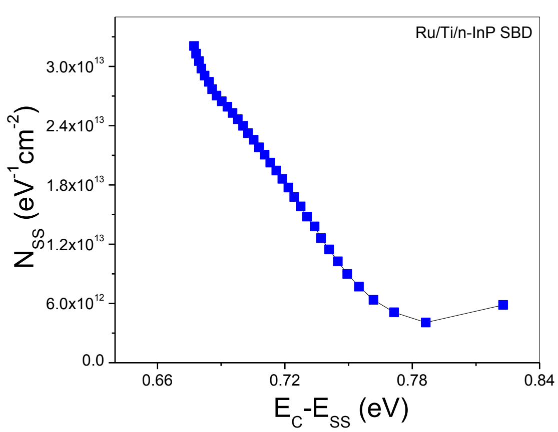

Fig.5:- Profiles of interface state density distribution as a function of E_c-E_{SS}.

Conclusion:-

The electrical properties of Ru/Ti/n-InP Schottky barrier diode were studied using current-voltage (I-V) measurement at room temperature. I-V, Cheung and Norde's methods are employed to calculate the ideality factor (n), series resistance (R_S) and barrier height (ϕ_b). The n and ϕ_b values from Cheung functions are compared with different methods and observed that there was a well coincidence with each other. The narrow deviation is observed between the parameters obtained from Cheung functions and Norde's functions. The interface state density has an exponential rise with bias from the midgap towards the top of the conduction band. It is clear that neglecting the presence of interfacial insulator layer, interface state density and series resistance can guide to overcome the defects of device characteristics.

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